



The Hydrogen-Fuelled Internal Combustion Engine

Zero-Carbon Update to a Familiar Energy Converter

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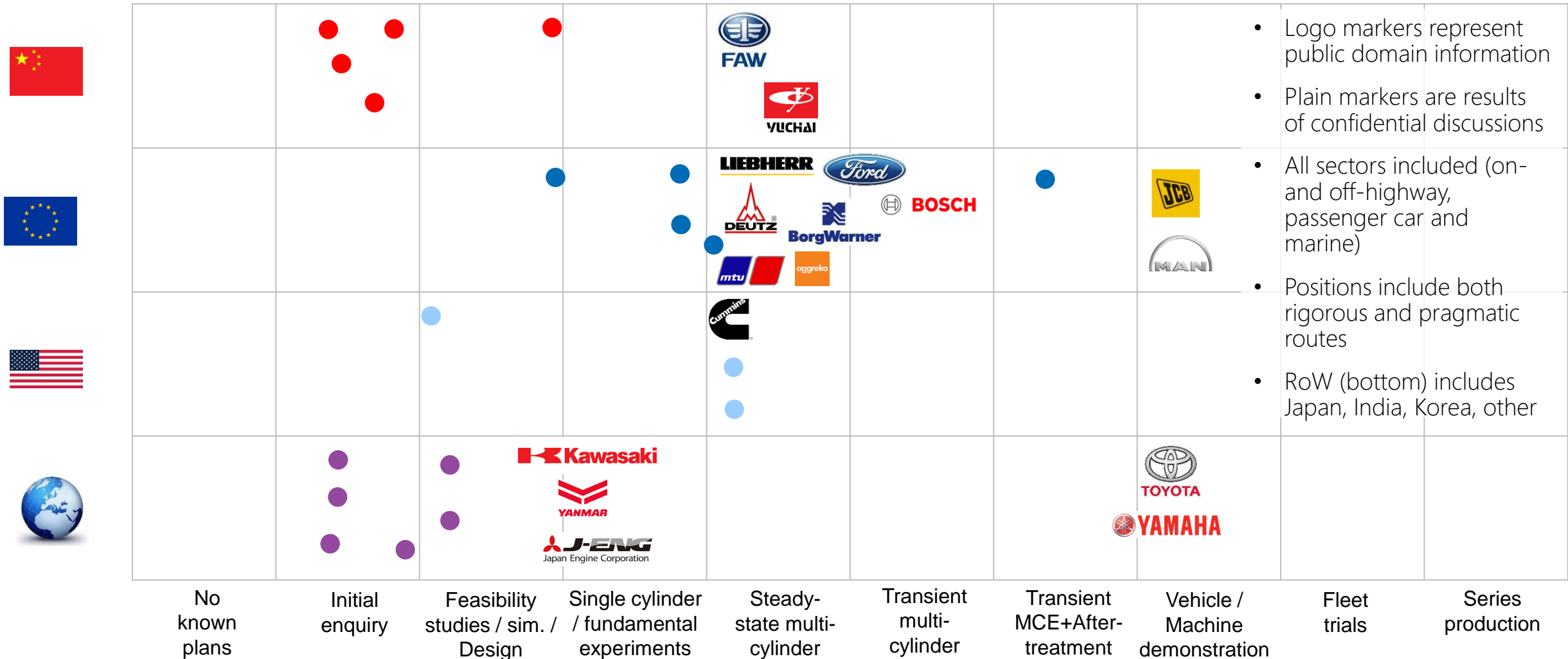
WHO'S DOING WHAT

RICARDO PROTEUS SINGLE CYLINDER RESEARCH ENGINE

HYDROGEN COMBUSTION CHARACTERISATION

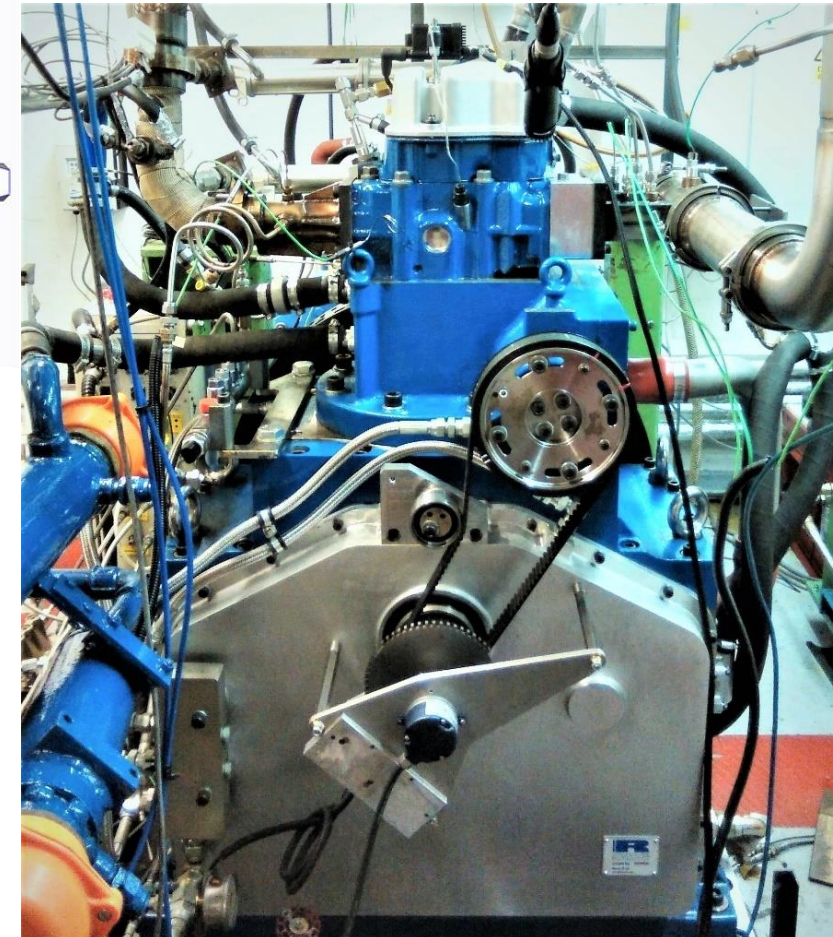
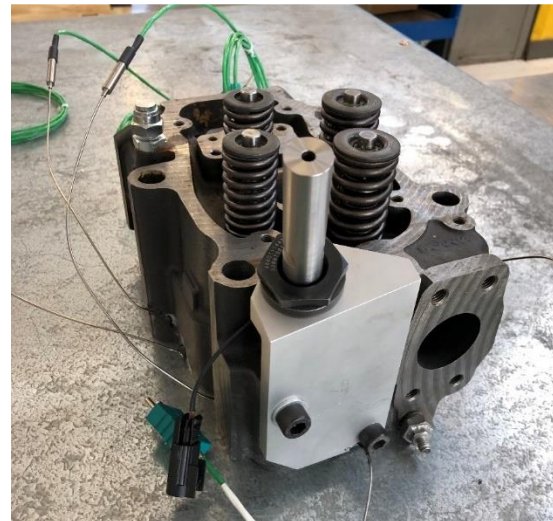
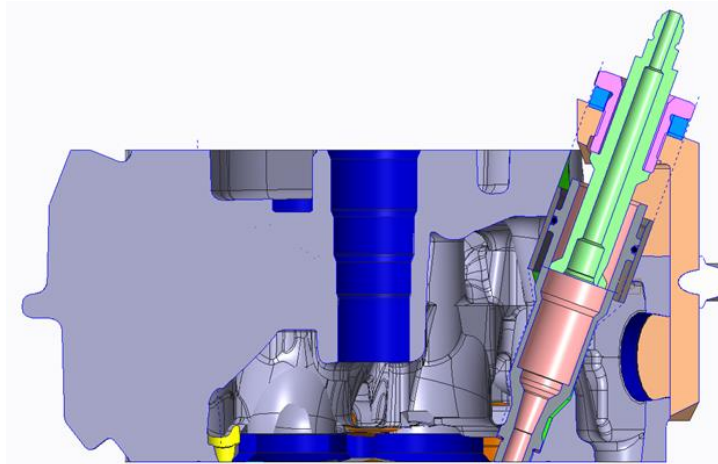
MULTI-CYLINDER DEMONSTRATION

DESPITE LOWER PUBLICITY, MANY TRANSPORT AND MACHINE INDUSTRY ORGANISATIONS ARE INVESTIGATING HYDROGEN COMBUSTION ENGINES



RICARDO IS RUNNING A “PROTEUS” SINGLE CYLINDER RESEARCH ENGINE FOCUSSING ON HYDROGEN COMBUSTION CHARACTERISATION

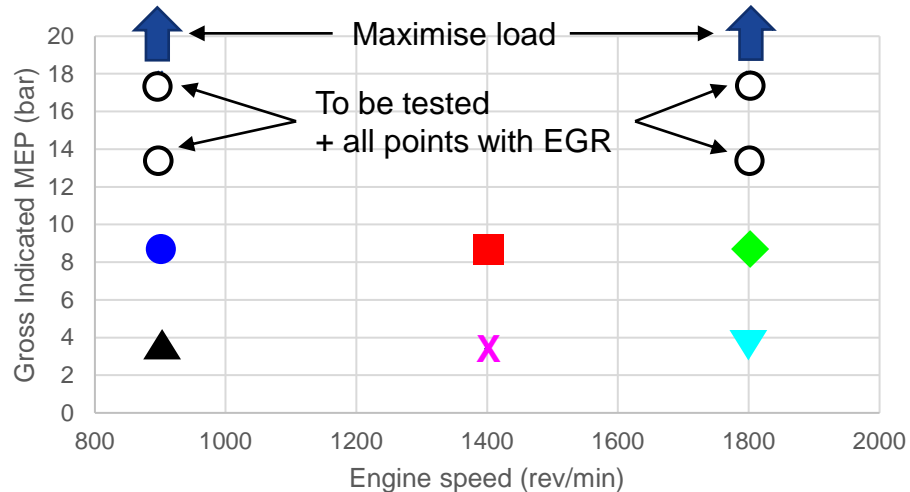
- 2017 Ricardo Proteus engine
 - 131mm x 158 mm → 2.13 litres
 - Volvo D13 piston & rod, Scania OC13 head
 - Side mount DI, BorgWarner DI-CHG 6.2
 - 12.5 compression ratio, moderate swirl
 - **Experimental programme ongoing**
- Primary objectives
 - Characterise combustion & response to experimental parameters
 - Parameters:
 - λ , EGR, injection and ignition timing, speed and load
 - Variables:
 - NO_x, η_{th} , boost requirement, P_{max} , T_{exh} , performance potential, knock, pre-ignition



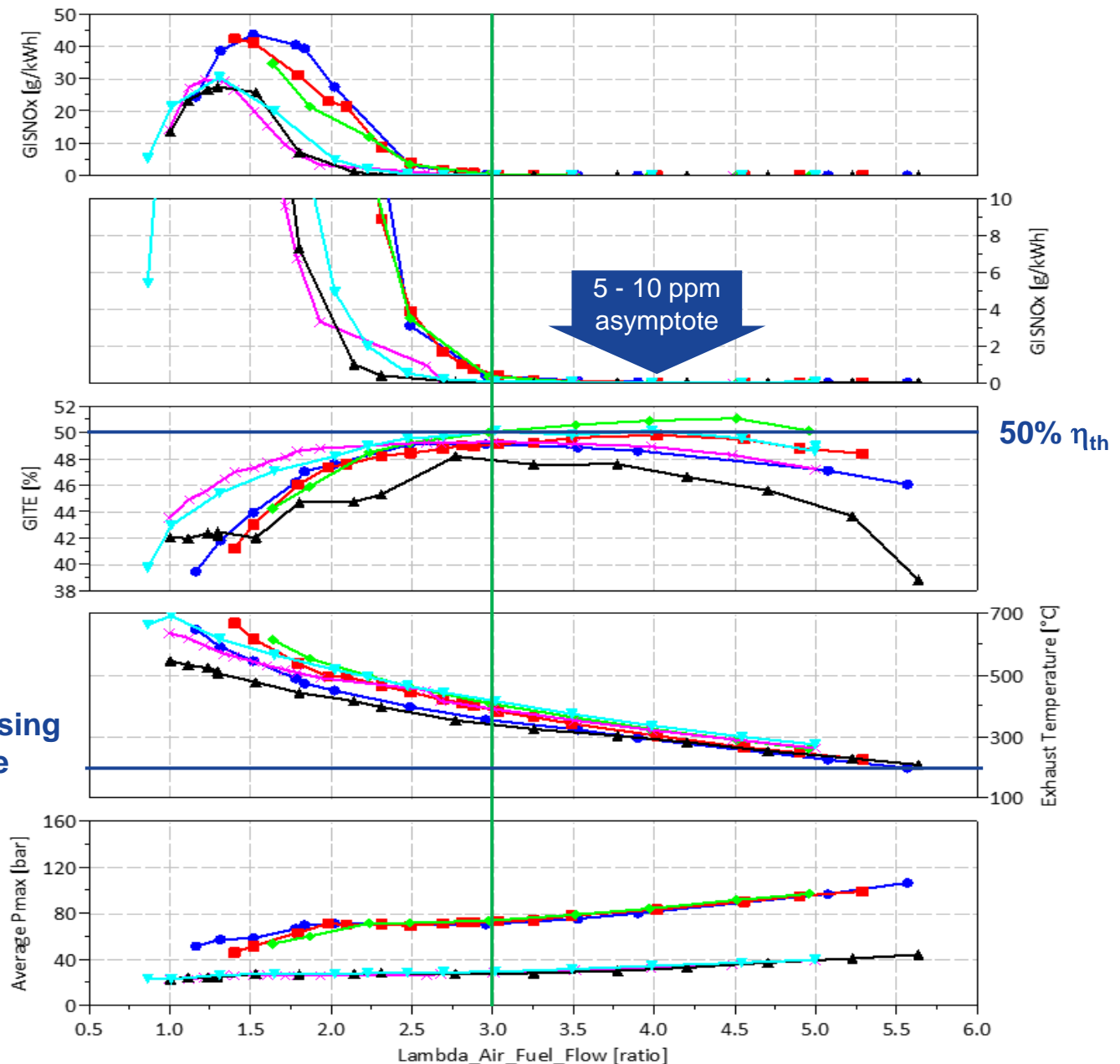
University of Brighton

PROTEUS DATA - HIGH LEVEL

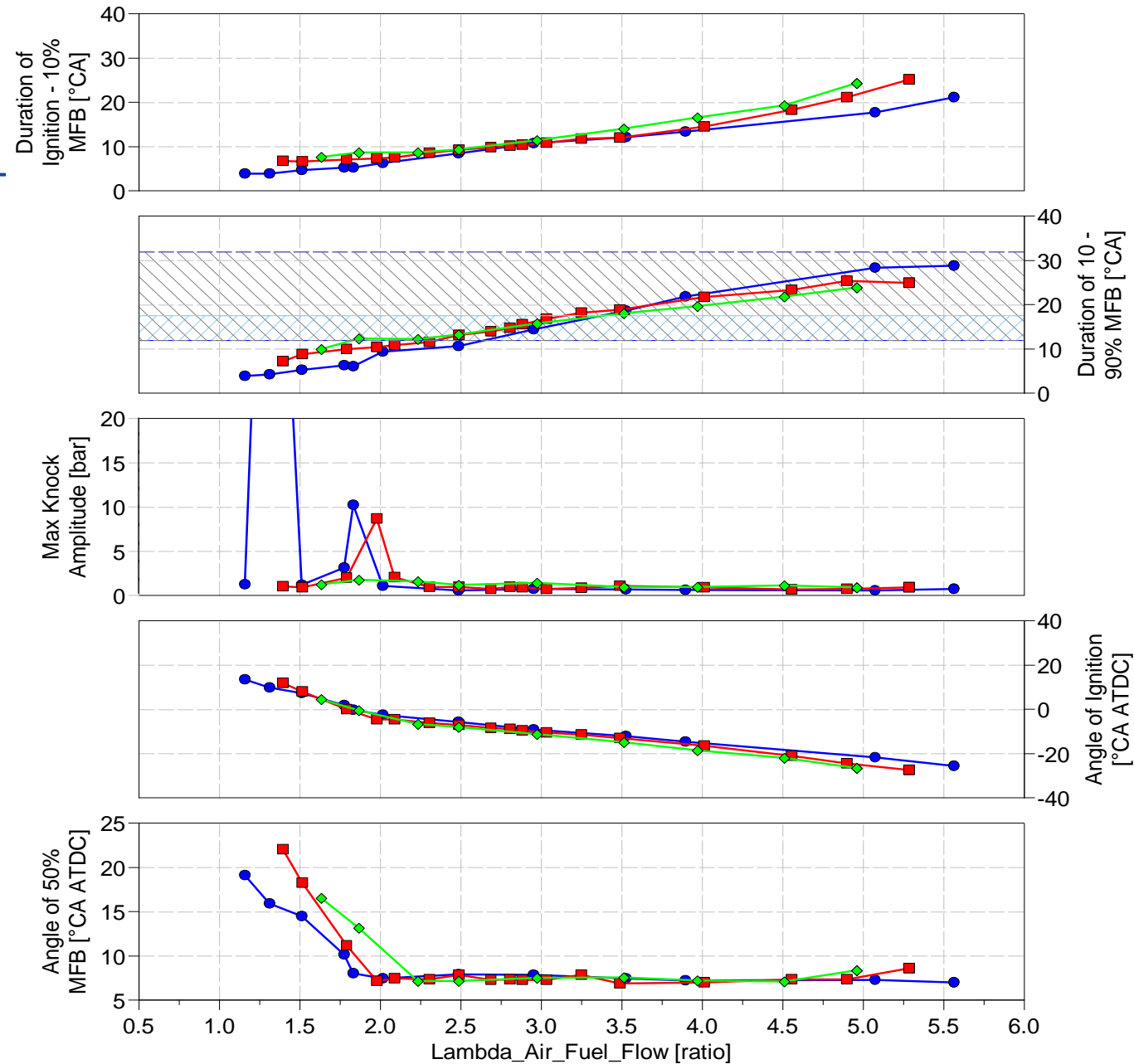
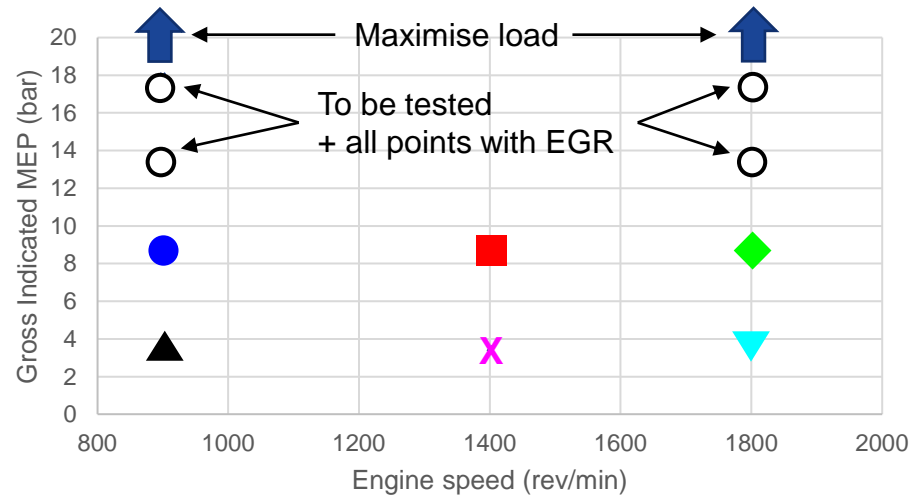
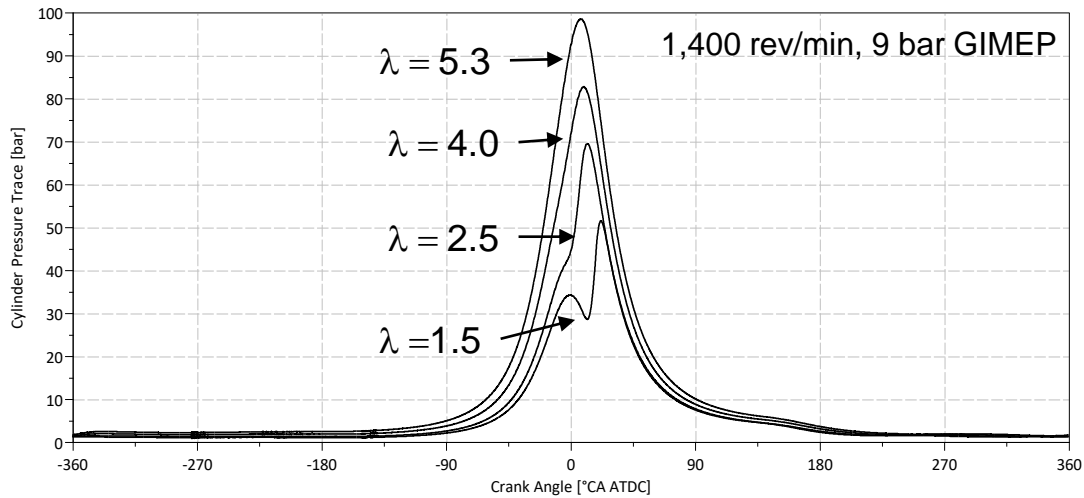
- Controlled and stable $\lambda \sim 1.2$ to $\lambda \sim 5$
- GISNOx shows near zero asymptote from $\lambda \sim 2.5 \rightarrow 3.0$
- GITE peak coincides with low GISNOx
- Exhaust temperatures high enough for SCR operation
 - Support lower lambda for transient response
- Pmax moderate throughout testing so far.



SCR dosing
Feasible



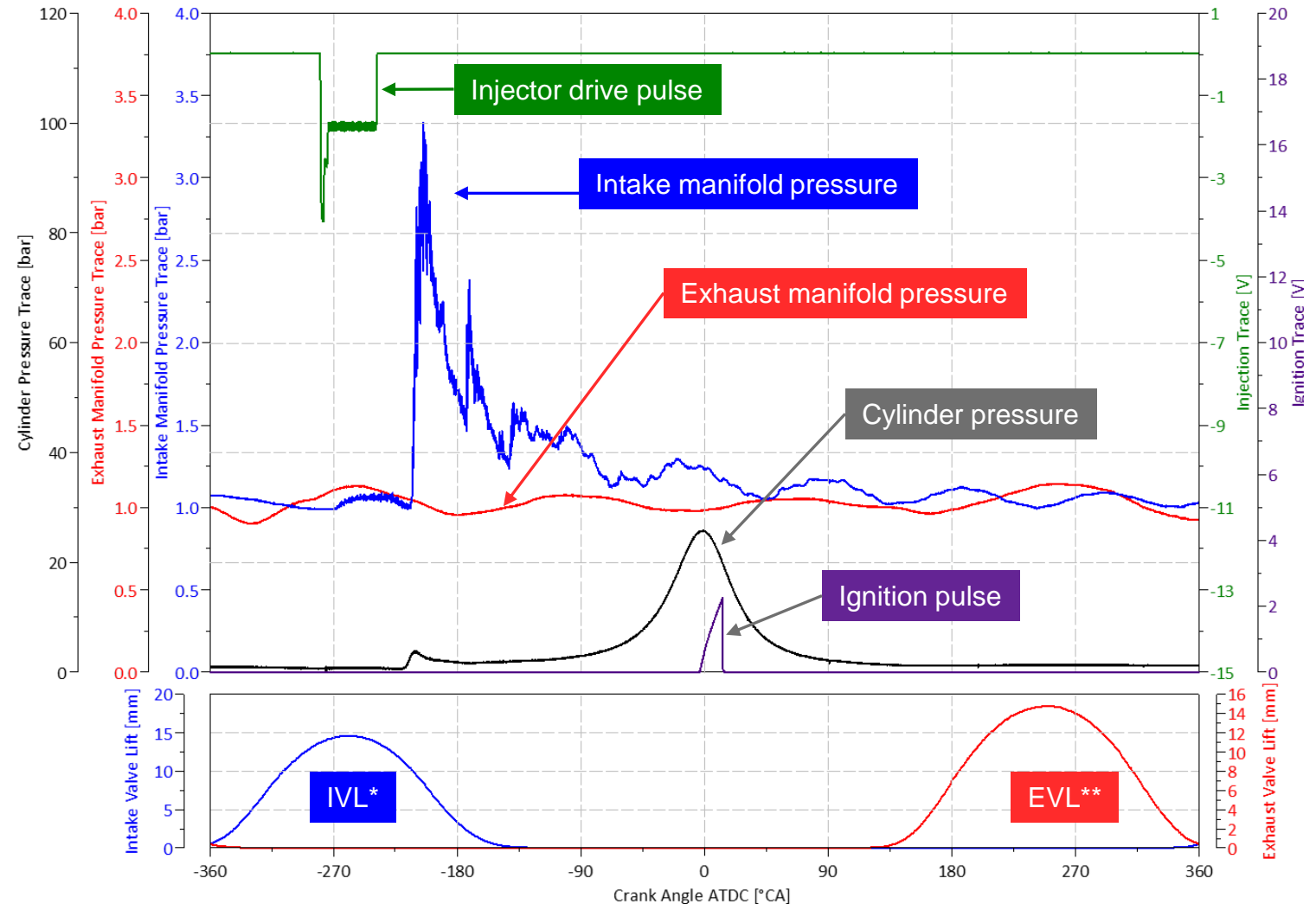
COMBUSTION CHARACTERISATION



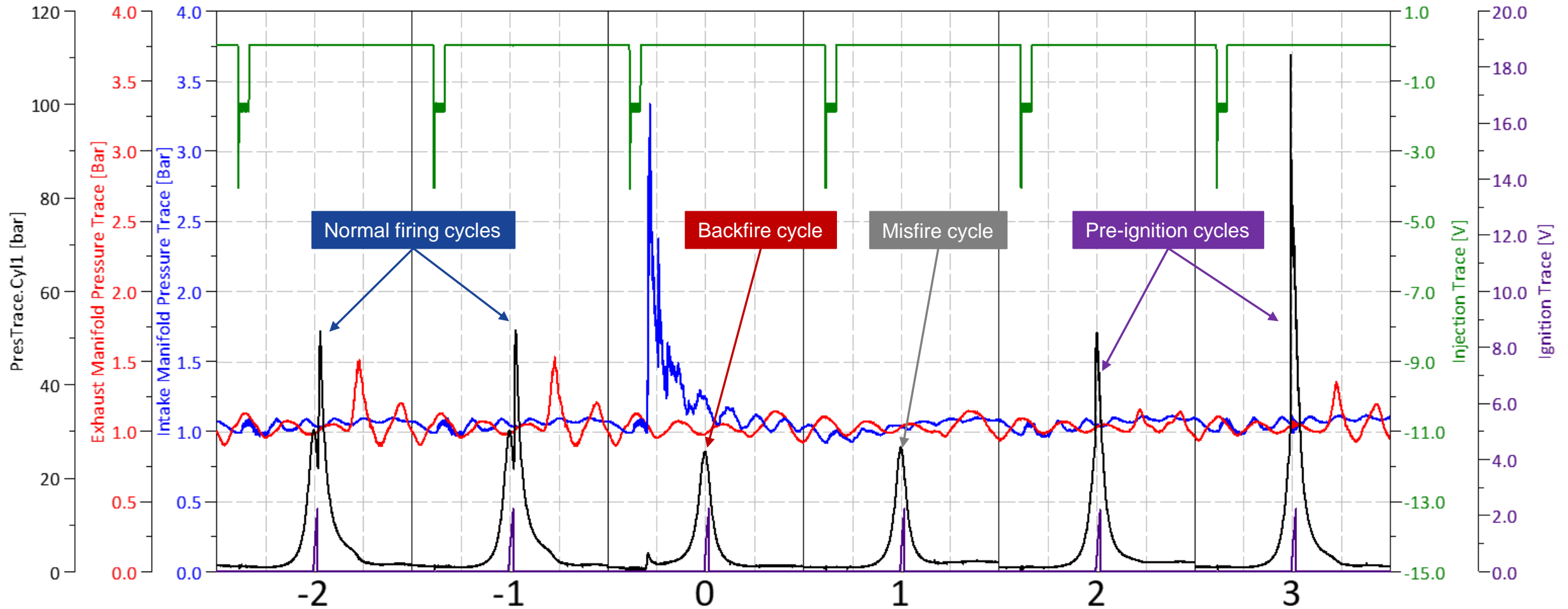
AT LOW LAMBDA COMBUSTION ANOMALIES ARE OBSERVED, EVEN AT MODERATE LOAD

- Example of a backfire event
- 900 rev/min, 9 bar GIMEP
- $\lambda = 1.1$

Event [all °CA ATDCf]	From	To
Injection	-280	-239
Intake Valve Lift (1mm with hot lash)	-354	-161
Pre-ignition	-215	



PRE-IGNITION EVENTS MAY HAVE CONSEQUENCES FOR SUBSEQUENT CYCLES



WHERE NEXT? - HIMET MULTICYLINDER

Hydrogen Integration in a Maritime Energy Transition

- Funded by UK Department for Transport in the Clean Maritime Demonstration Competition
- **Demonstrate the performance, emissions and efficiency potential of a hydrogen-fuelled marine propulsion engine, achieving full power and zero carbon emissions**
- Investigate the scale-up for fuel cell systems to include multiple stacks with common balance of plant to improve packaging weight and cost - for auxiliary power
- Project commenced September 2021



12.7 LITRE MULTICYLINDER ENGINE NOW RUNNING

- Ricardo-modified Scania OC13 NG
- Equipment
 - Direct and port injectors
 - Variable geometry turbine turbocharger
 - Exhaust Gas Recirculation
 - Bespoke controls
- Targets
 - 315 kW at 1,800 rev/min
 - 20 bar BMEP at 1,400 rev/min
 - <2.0 g/kWh NOx over E3 cycle (IMO Tier 3)
- 100% Ricardo assets - available to customers for experimental work after HIMET
- Specific hydrogen engine test cell - up to 450 kW shaft output
- ~400 line safety action/reaction matrix in PLC!





THANK YOU

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